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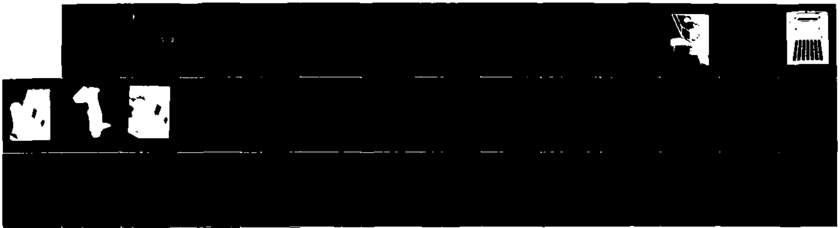

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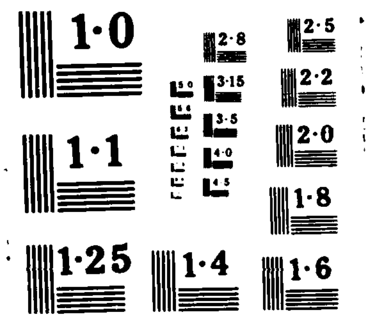
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Technical Memorandum 17-87

COMPARISON OF ALPHANUMERIC DATA ENTRY METHODS FOR ADVANCED HELICOPTER COCKPITS

Frank J. Malkin
Kathleen A. Christ

September 1987
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U. S. ARMY HUMAN ENGINEERING LABORATORY
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In this study, three methods of data entry were compared for entering navigation coordinate sets: (a) connected-word voice recognition, (b) keyboard, and (c) thumb-controlled switch. The subjects, 12 active Army aviators, entered the data as a sole task and also while flying a helicopter simulator equipped with a computer-generated, external scene. The different data entry methods were compared for time to enter the data, for errors, and for the effect on flight performance.

Results showed that the keyboard was faster and resulted in fewer errors than the other two data entry methods. The time to enter data by voice was increased by the high nonrecognition rate (12 percent) and the error correction procedure. An overall 81 percent recognition accuracy rate was achieved in this study, with individual rates varying from 58 percent to 99 percent. Based on a subjective questionnaire, the majority of subjects still preferred to enter data by voice.

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COMPARISON OF ALPHANUMERIC DATA ENTRY METHODS

FOR ADVANCED HELICOPTER COCKPITS

BACKGROUND

The visual and manual workload of U.S. Army helicopter crews is extremely high. Flying while concurrently navigating, monitoring aircraft subsystems, and performing gunnery or reconnaissance tasks at altitudes below treetop level often requires more time and attention than is available. The U.S. Army is currently formulating concepts for a family of light helicopters (LHX) with automation levels that may allow these tasks to be performed by a single pilot. Obviously, computer technology is required to automate the cockpit. At the present time, keypads or keyboards are required for entering alphanumeric data into computerized systems. There is concern that the visual and manual demands of operating a keyboard in flight will contribute to an even greater workload. In this study, two alternatives to keyboards are considered: automatic voice recognition and data entry through a single, thumb-controlled switch.

Previous research has been performed comparing voice and keyboard data entry methods in airborne applications (Aretz, 1983; Wyatt, 1983; Malkin & Christ, 1985a). These studies indicate that data entry tends to be faster by keyboard than by voice. However, the aviators who participated preferred voice data entry because it was perceived as requiring less effort. The aviators in the Aretz study qualified their preference by stating that when data entry is the sole task (not performed concurrently with flying) or when data input strings are short, the keyboard is the preferred method.

These three studies used isolated-word voice recognition systems that require a 1-to-2-second pause between each utterance. A connected-word voice recognition system is used in this study. The connected-word voice recognition system accepts a string of predefined utterances without pauses.

A pilot study was conducted to determine if the connected-word voice recognizer would decrease the time to input alphanumeric data strings enough to compete with the keyboard method. Subjects entered the data strings on an isolated-word voice recognition system and a connected-word voice recognition system. The isolated-word system required the subjects to pause between each utterance. On the connected-word system, pauses were not permitted. If the subject paused in the middle of the string, the recognizer did not accept the input. The subject then had to begin again. The times obtained from this study showed that the connected-word system was significantly faster than the isolated-word system. There were also fewer errors with the connected-word system.

Automatic voice recognition appears to have potential as an alternative to keyboard data entry, but the evidence to date suggests that speech technology has not yet fully matured for use in the high-stress environment of the helicopter cockpit (Malkin & Christ, 1985b).

As an alternate manual method to the keyboard, the Aviation and Air Defense Division, Human Engineering Laboratory (HEL), Aberdeen Proving Ground, Maryland, has developed a data entry technique that uses a thumb-controlled switch to scroll alphanumeric characters onto a video display. The hardware and software for this data entry technique have been installed in an HEL advanced helicopter flight simulator known as the Cockpit Research, Experimentation, and Workload (CREW) Simulator.

OBJECTIVE

The objective of this investigation was to conduct a laboratory flight simulation to compare a cockpit keyboard, a thumb-controlled switch, and a connected-word voice recognizer for data entry of navigation map coordinate sets. The data entry methods were compared under two task conditions: (a) the entry of universal transverse mercator (UTM) coordinate sets as the sole task performed and (b) the entry of UTM coordinate sets performed concurrently with controlling a helicopter simulator while flying a computer-generated external scene. The time and error differences among the three methods of data entry were evaluated along with flight performance data to determine the merits of each method. In addition, a subjective questionnaire was used to determine if a user preference exists.

METHODOLOGY

Subjects

Data were collected using 12 Army aviators assigned to Aberdeen Proving Ground (APG). The subjects had an average of 2,580 flight hours in rotary-wing aircraft, with a range of 1,100 to 5,000 hours. The average age was 38, with a range of 32 to 50. Nine subjects had previous experience using voice recognition systems as a result of participating in previous investigations. Six reported having previous experience with keyboards, but none had previous experience with the keyboard arrangement used in this investigation. None had previous experience with the thumb-controlled switch.

Apparatus

The following apparatus was used:

1. Flight simulator - The CREW Simulator consists of a cockpit cab with advanced controls and displays and an "out-the-window" scene produced by computer-generated imagery (CGI) (Figure 1). The CGI system models a gaming area of 5 square miles consisting of trees, hills, rivers, roads, and buildings. A 40-by 40-degree field of view is projected on a 6-foot by 6-foot screen in the front of the cockpit cab. The cockpit controls and displays are driven by a VAX 11/750® computer. A VAX 11/780® computer is used for the CGI and experimental data collection. Clark and Pferdner (1985) provide more detailed information concerning the CGI system.

Figure 1. Cockpit Research, Experimentation, and Workload (CREW) Simulator.

2. Plasma display - The display provides data entry feedback for each data entry method.

3. Keyboard - The keyboard layout, which is one recommended by Butterbaugh and Rockwell (1982), has separate keys for each alpha and each numeric character. The keyboard and plasma display are located in the simulator cockpit on the left console adjacent to the collective lever flight control (Figures 2 and 3).

4. Thumb-controlled switch - The thumb-controlled switch is a "Chinese hat-type" switch located on top of a standard cyclic flight control handgrip (Figure 4). The switch has four positions -- up, down, left, and right. The plasma display is positioned on the upper center portion of the instrument panel (Figure 5). The intent was to provide the pilot with the capability of entering data while keeping his hands on the flight controls and his head up.

5. Connected-word voice recognizer - The Verbex® Series 4000 connected-word voice recognition system was used. It makes the entry of predefined strings of words without pauses between the words possible. Data entry feedback was provided on the plasma display in the same location as the thumb-controlled switch.

6. DECtalk® voice synthesizer - The voice synthesizer provides seven different computer-generated voices. The DECtalk® default voice, a typical male voice, was used during the study to prompt the subjects.

7. Voice-activated switch - The switch signaled the computer when the subject began entering data by voice. The computer then began collecting data.

8. Video tape recorder - This was used for data collection.

Procedure

Training and testing of one data entry method was completed before the next data entry method was presented. The presentation order of the data entry methods and the flight tasks was counterbalanced.

Each subject was given an overview of the experiment describing the purpose of the study and the procedures to be followed. They were permitted to ask questions concerning the investigation and their involvement in the study. Upon completion of the overview, a background questionnaire was administered (see Appendix A).

Training

Regardless of the order in which the data entry methods were tested, template enrollment for the voice recognition system occurred first. The format of the data to be entered, as well as the correction procedures

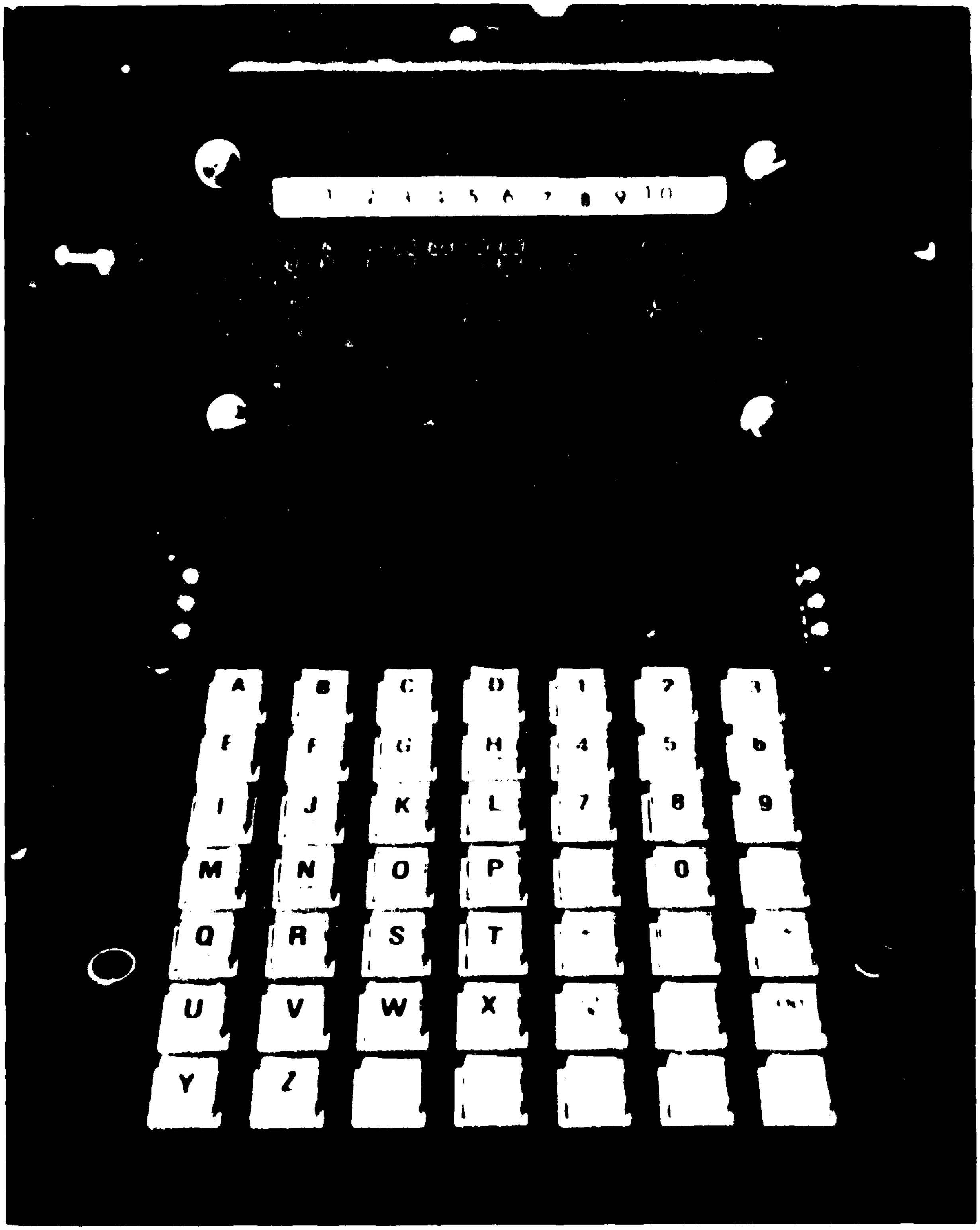

Figure 2. Keyboard layout.

Figure 3. Keyboard and display location.

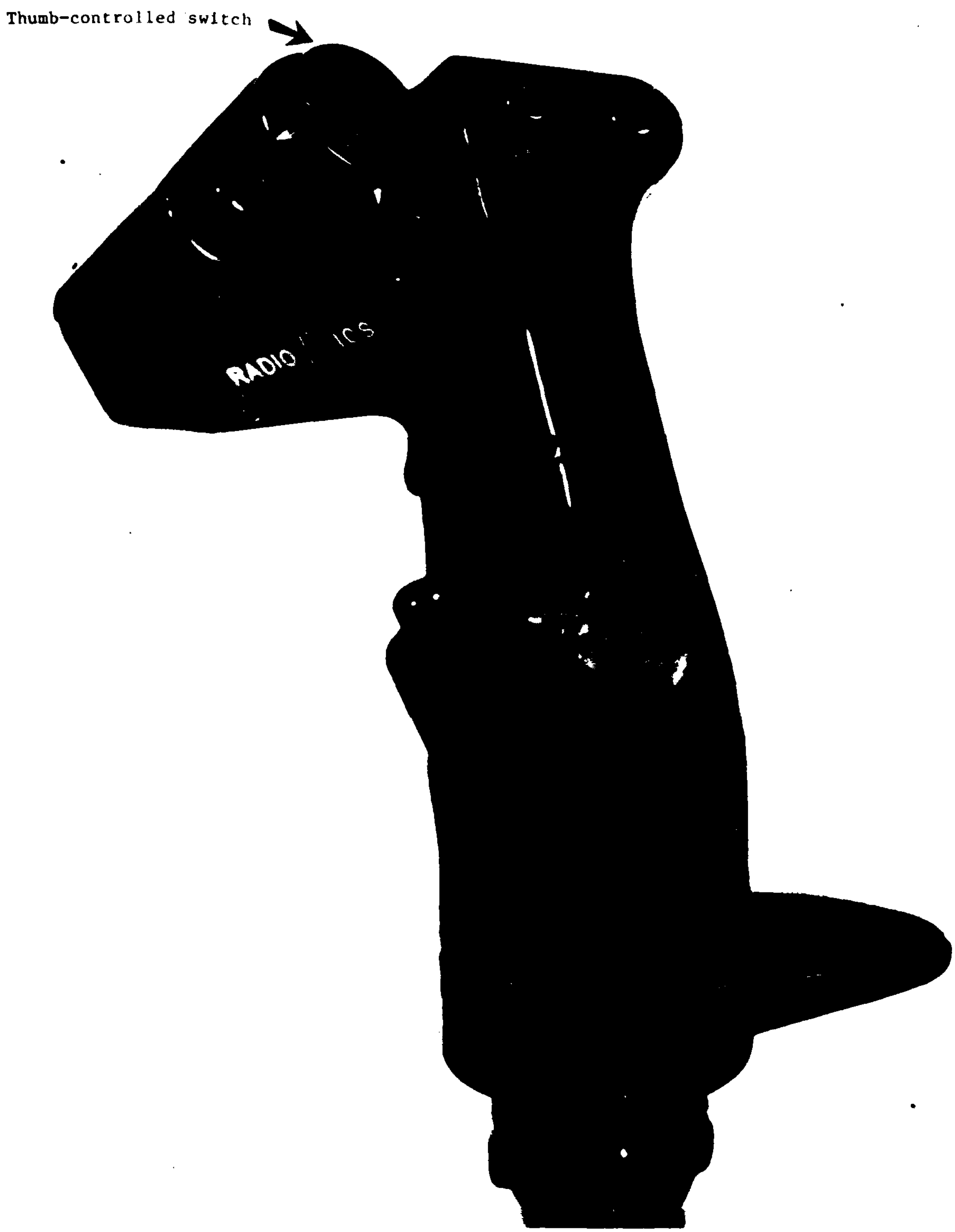

Figure 4. Thumb-controlled switch.

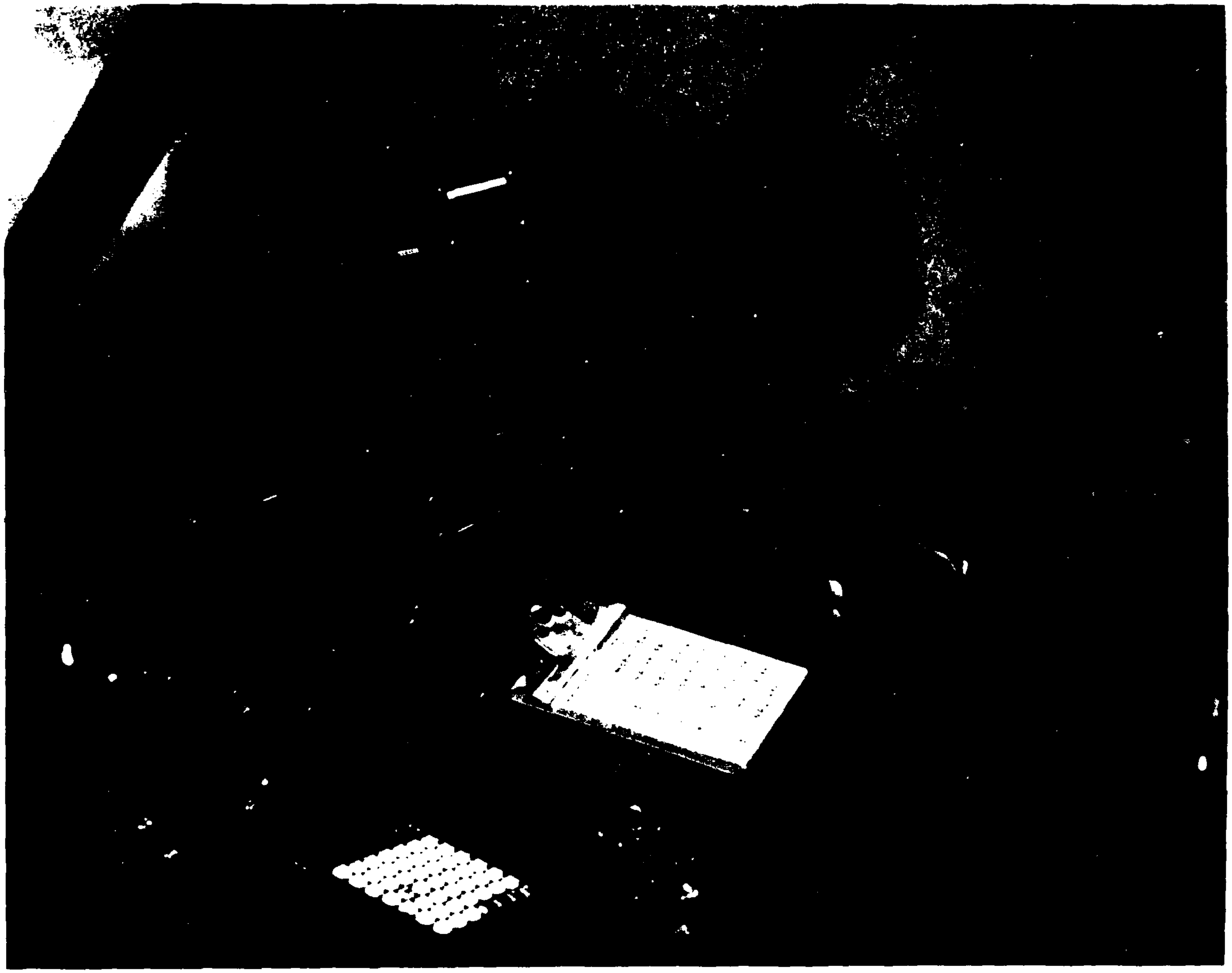

Figure 5. Switch and display location.

available, was outlined and explained. The vocabulary for this study consisted of 20 words. The vocabulary and grammar structure are included in Appendix B.

Template enrollment involves repeating each vocabulary word twice, followed by speaking character strings formulated randomly by the recognition system to form voice templates. Speaking the character strings is referred to as embedded training and is required for operation of a connected-word voice recognizer. It provides the recognizer with samples of how the subject pronounces certain words in the middle of a string of words.

Two training passes were used to form the subject's voice templates. During the training session, the subject was seated in the simulator and wore his flight helmet with a standard aviation microphone. The word or words to be spoken appeared on a cathode-ray tube (CRT) located on the left side of the simulator. The subject controlled the pace at which the words were presented. The enrollment process took approximately 30 minutes to complete.

After the initial voice enrollment was completed, a recognition test was performed to determine if any individual words required retraining. The subject spoke each vocabulary word and several strings of words two times. Any words that were not correctly recognized both times were retrained.

Once the voice enrollment session was complete, the subject received training on the flight simulator used in this study. The flight display and the unique flight characteristics of the simulator were explained to the subject. Two practice flight sessions, each about 30 minutes long, were provided to familiarize the subject with the simulator and the predefined flight course.

One potential subject was precluded from participating in the study because he was unable to adapt to the flight-handling qualities of the simulator.

Before the voice data entry method was tested, subjects practiced entering 16 waypoint coordinate sets. A coordinate set consists of two alpha characters followed by eight digits (AB12345678). The subjects could enter a coordinate set one character at a time or any combination up to all 10 characters at one time. The inputs were displayed on the plasma display located on the front console of the simulator. The error correction procedures were also practiced to ensure that the subject understood the correction process of each method.

Two error correction procedures were available to correct any error. The word CLEAR could be spoken to erase the display. All characters entered up to that point would be erased. The subject would then re-enter the coordinate set from the beginning. The second option was taken from a study performed at the Naval Postgraduate School (Poock and Martin, 1985). The string "POSITION (digit) MAKE-IT (alphanumeric)" had to be spoken all at once without any long pauses between words. The "digit" could be a number 1 through 10 corresponding to the position of the error in the coordinate set. Above each position on the plasma display, the number corresponding to that position was indicated. The "alphanumeric" referred to the correct number or alpha character to be input. For example, if it was necessary in the coordinate set

AB12945678 to change the digit 9 to the digit 3, the command to be spoken would be "POSITION FIVE MAKE-IT THREE." Once the proper coordinate set was displayed, the word ENTER was spoken to enter the coordinate.

A subject was considered proficient if, after the practice session, five coordinate sets were entered correctly. A second subject had to be replaced due to poor performance on the voice recognition system. After three training passes on the entire vocabulary, along with additional retraining on the individual words ENTER, EIGHT, and CORRECTION, a coordinate set could not be correctly entered. The subject had prior experience with using an isolated-word voice recognition system without any difficulty.

Training on the keyboard method of data entry consisted of an explanation of data entry and the error correction procedures, followed by a practice session. The keyboard used had separate keys for the alpha and numeric characters. Therefore, only one key press was required to enter any character.

Two error correction procedures were available for the keyboard data entry method. The subject could depress the CLEAR key, in which case the data entered up to that point would be erased. The correct coordinate set could then be entered from the beginning. The other correction procedure was the use of the backward and forward arrow keys. Each time one of the keys was depressed, the cursor would move one space forward or backward. The subject could then enter the correct characters, starting at the position of the cursor. Once the correct coordinate set was displayed, the ENTER key was depressed to enter the coordinate into the system.

Subjects were able to practice entering and correcting 16 coordinate sets using the keyboard. The characters were displayed as they were entered on the plasma display, located adjacent to the keyboard. The same proficiency criterion used for voice data entry was also used for keyboard data entry.

The thumb-controlled switch located on the cyclic was the third method of data entry. The switch had four positions: left, right, up, and down. The up and down positions controlled the forward and backward scrolling of the alphanumeric characters; the left and right positions controlled the position of the cursor. To enter a character, the subject held the switch either up or down, scrolled through the alphabet or numbers until the desired one to be entered was displayed, and then moved the cursor to the next position in the coordinate set. Only alpha characters were displayed in the first two positions and only digits, in the last eight. The characters were displayed on the plasma display located on the front console of the simulator.

Error correction was handled by positioning the cursor under the character to be corrected by using the left or right position on the switch, then rescrolling through the alphabet or numbers until the correct entry was displayed. To enter the correct coordinate set, the switch was pushed to the right.

Before each method of data entry was tested, each subject was given a practice flight in the simulator, during which time four coordinate sets were entered. This gave the subjects a feel for how the test session would be conducted.

Testing

There were two testing conditions: a flight condition and a no-flight condition. Each subject entered eight UTM coordinate sets for each test condition. The coordinate sets, which were selected from a military map of the Fulda Gap area of Germany, were located on a kneeboard attached to the subject's leg. A different set of coordinates was used in each condition. The subject was tested in both conditions using one data entry method before proceeding to the next data entry method. Flight gloves were worn by the subjects during all training and testing conditions.

In the flight condition, each subject entered the coordinate sets while flying the predefined course in the simulator. The flight course was along a winding riverbed lined on both sides by trees and hills. Each subject was instructed to fly the course as fast as possible while remaining at an altitude at or below treetop level and centered on the riverbed. Directional poles were positioned at river and road intersections to assist the subject in staying on course. The DECtalk® voice synthesizer gave additional directional guidance to the subject.

The computer monitored progress along the course, and at predefined locations the subjects were prompted to enter each coordinate set. The prompt was given by the voice synthesizer. The subjects were instructed to enter data as they would in an actual flight; that is, as quickly and as accurately as possible while maintaining safe operation of the aircraft.

In the no-flight condition, data entry was performed as a sole task. The subject was seated in the simulator cockpit and entered the coordinate sets. The voice synthesizer prompted the subject when to enter each coordinate. A random time between 5 to 12 seconds was allowed between each waypoint. These delay times were the same for each subject.

When all testing was completed, each subject was given a subjective questionnaire to complete (see Appendix C).

Data Collection

All data, except for the voice data entry errors, were collected by the computer. The data collected were as follows:

1. Response time - Response time is the time from when the subject was prompted to when data entry began. When voice data entry was being tested, the prompt to enter data also turned on the voice-activated switch.

2. Input time - Input time is the time from the start of data entry to the completion of data entry. When voice data entry was being tested, the voice-activated switch was used to record the inputs made by the subjects. When the other two methods were being tested, the character inputs indicated the input time.

3. Total time - Total time is the time from when the subject was prompted to enter data to the completion of data entry. It was recorded by adding the response time and the input time.

4. Errors - Voice data entry errors were scored using the best-case pattern matching procedure as outlined by the National Bureau of Standards (Pallett, 1985). The errors consisted of the following:

a. Nonrecognition - The recognizer did not accept the input.
b. Misrecognition - The recognizer misunderstood the input.
c. Insertion - The recognizer inserted a character into the string put in by a speaker.
d. Deletion - The recognizer dropped a character from the input string.
e. Subject error - The speaker inputted the wrong character.
f. Error of technique -The speaker inserted lengthy pauses into the character string.

These errors were collected off the video tape recordings made during the test sessions. Keyboard and thumb-controlled switch errors consisted only of subject errors. The computer compared the individual character entries made by the subject to the correct character that should have been entered. Errors were then recorded.

5. Flight performance - Flight performance data were sampled four times per second, averaged, and printed once every second. The flight performance data recorded were airspeed, altitude, and flight path deviation. Flight path deviation was measured as the root-mean-square (RMS) error from the set path. The differences between "before data entry" and "during data entry" for airspeed, altitude, and flight path deviation were compared.

Experimental Design

The data collected were broken down into two groups to be analyzed separately. In Design 1, a 2 x 3 x 12 factorial design with repeated measures on the 12 subjects was used. The within-subject factors were data entry methods (voice, keyboard, and thumb-controlled switch) and task conditions (flight, no flight). The dependent variables were response time, input time, and errors.

A 3 x 12 factorial design with repeated measures on the subjects was used for the second design. The within-subject factor was data entry methods (voice, keyboard, and thumb-controlled switch). The dependent variables were the average differences between before data entry and during data entry for airspeed, altitude, and flight path deviation.

The presentation order of the data entry methods, as well as the task conditions, was counterbalanced.

RESULTS

The data were analyzed using the Statistical Package of the Social Sciences (SPSS) User's Guide (SPSS, 1986). In Design 1, subjects were measured across the various treatment combinations for each dependent variable. Because the measures were highly correlated, a multivariate analysis was performed using the univariate repeated measures model with subjects considered a random factor. Summary analysis tables for the measures analyzed in this design are in Appendix D. As a confirmatory procedure, the results achieved using this procedure were compared with the results obtained using a multivariate repeated measures model. The results agreed.

Design 2 was analyzed similarly to Design 1. Subjects were measured across data entry method and task condition for the flight performance measures. A multivariate analysis was again performed using the univariate repeated measures model with subjects considered a random factor.

Confidence intervals (95th percentile) were calculated to test for differences between the means for each of the significant dependent measures. Results of the analyses for the various dependent measures are described in the following sections. The mean, standard deviation, and confidence interval tables are in Appendix E.

Response Time

Subjects were able to respond significantly faster to the prompt to enter data during the no-flight task condition than during the flight task condition, $F(1, 11) = 29.25$, $p < .05$. There also was a significant interaction between data entry method and task condition, $F(2, 22) = 11.7$, $p < .05$. During the no-flight task condition, subjects responded significantly faster to the prompt when the keyboard was used to enter data as opposed to voice or the thumb-controlled switch. However during the flight task condition, subjects responded significantly faster using either voice or the thumb-controlled switch to enter data rather than with the keyboard method (see Figure 6).

Input Time

There was a significant difference between each data entry method for the mean input time, $F(2, 22) = 30.78$, $p < .05$. The keyboard method was the fastest mode, followed by the voice data entry method and then by the thumb-controlled switch method, under each task condition. Subjects were able to input data significantly faster during the no-flight task condition than during the flight task condition, $F(1, 11) = 25.21$, $p < .05$ (see Figure 7).

Total Time

A significant difference existed between the mean total times to complete data entry using each method, $F(2, 22) = 34.26$, $p < .05$. Subjects were able to respond and enter data faster during the no-flight task condition than

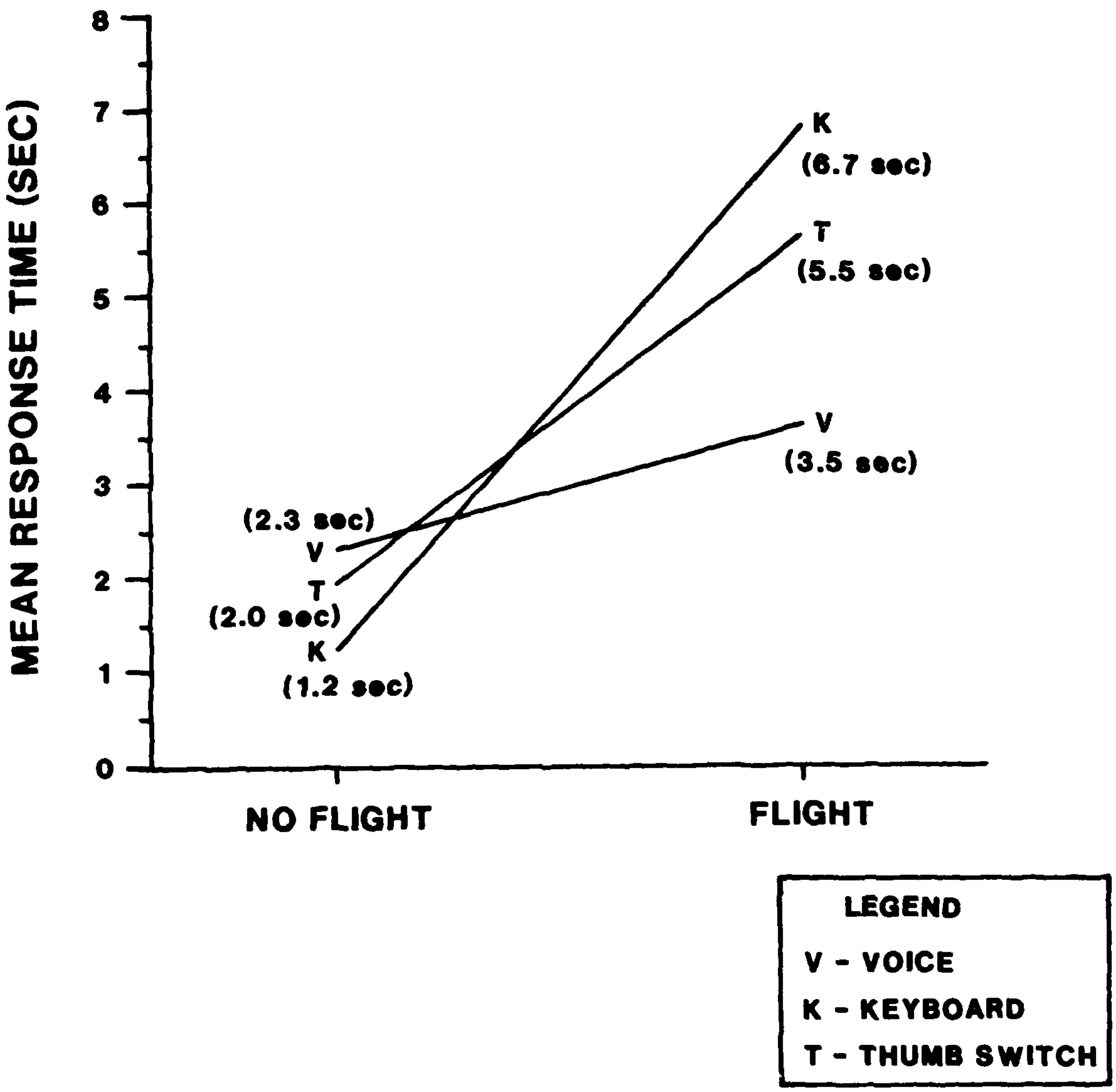

Figure 6. Mean response time.

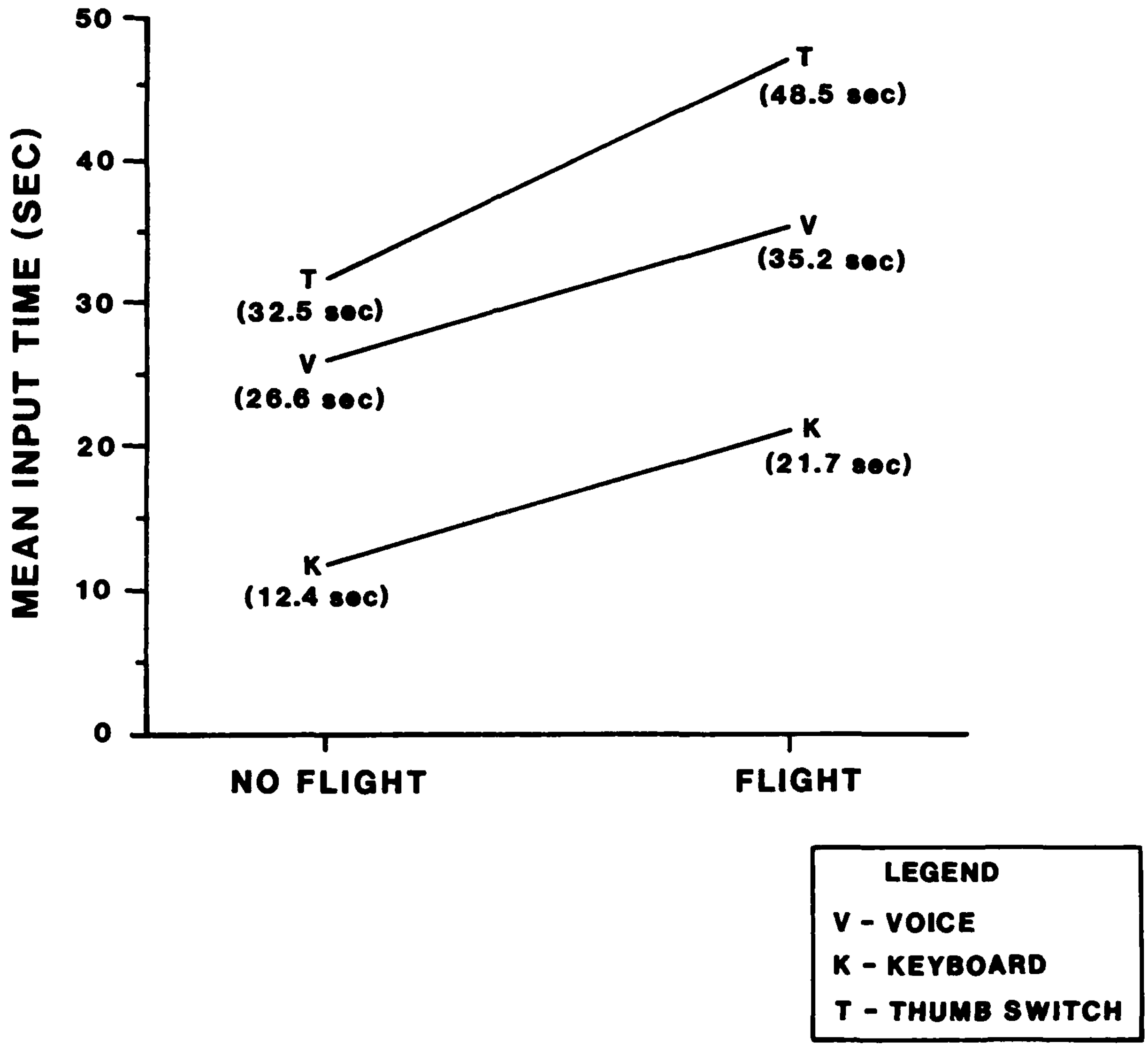

Figure 7. Mean input time.

during the flight task condition, $F(1, 11) = 31.17$, $p < .05$. During the no-flight task condition, the total time to enter data was significantly faster using the keyboard method than either the voice or thumb-controlled switch methods. During the flight task condition, the voice data entry and keyboard methods were significantly faster for overall total time than the thumb-controlled switch method (see Figure 8).

Errors

There were significantly more errors with voice data entry than with the keyboard or the thumb-controlled switch; $F(2, 22) = 20.30$, $p < .05$ (see Figure 9). The majority of the errors that were made using voice data entry are attributed to machine errors, not subject errors. When only subject errors were compared, no significant differences existed. An overall recognition accuracy of 81 percent was attained in this study. The recognition system correctly recognized 85.5 percent of the utterances when data entry was a sole task and 75.9 percent during the flight task condition. Recognition rates for the 12 subjects ranged from 58 percent to 99 percent. The ENTER command was consistently nonrecognized across subjects. In one case, it was misrecognized as the command CLEAR.

Airspeed

There were no significant differences for airspeed. While entering data using each of the three data entry methods, the subjects were able to maintain close to the same airspeed as they did before entering data. Table 1 shows the average difference in airspeed between flying before entering data and flying while entering data. The difference was computed by subtracting the average airspeed flown before entering data from the average airspeed flown while entering data. Therefore, the negative numbers in Table 1 indicate that a slightly higher airspeed was flown before data entry than during data entry for all three data entry methods.

Altitude

There was no significant difference between data entry methods for altitude. This would indicate that the subjects were unaffected by the method of data entry in their ability to maintain a consistent altitude. A significant difference did exist between subjects for the average altitude difference; $F(2, 22) = 1.84$, $p < .05$. The difference between subjects indicates that some subjects did not maintain the same altitude while entering data as they did before entering data. However, the method of data entry used had no bearing on the subjects' abilities to maintain a consistent altitude. The average differences in altitude are also shown in Table 1. The positive values indicate that a slightly higher altitude was flown during data entry than before data entry.

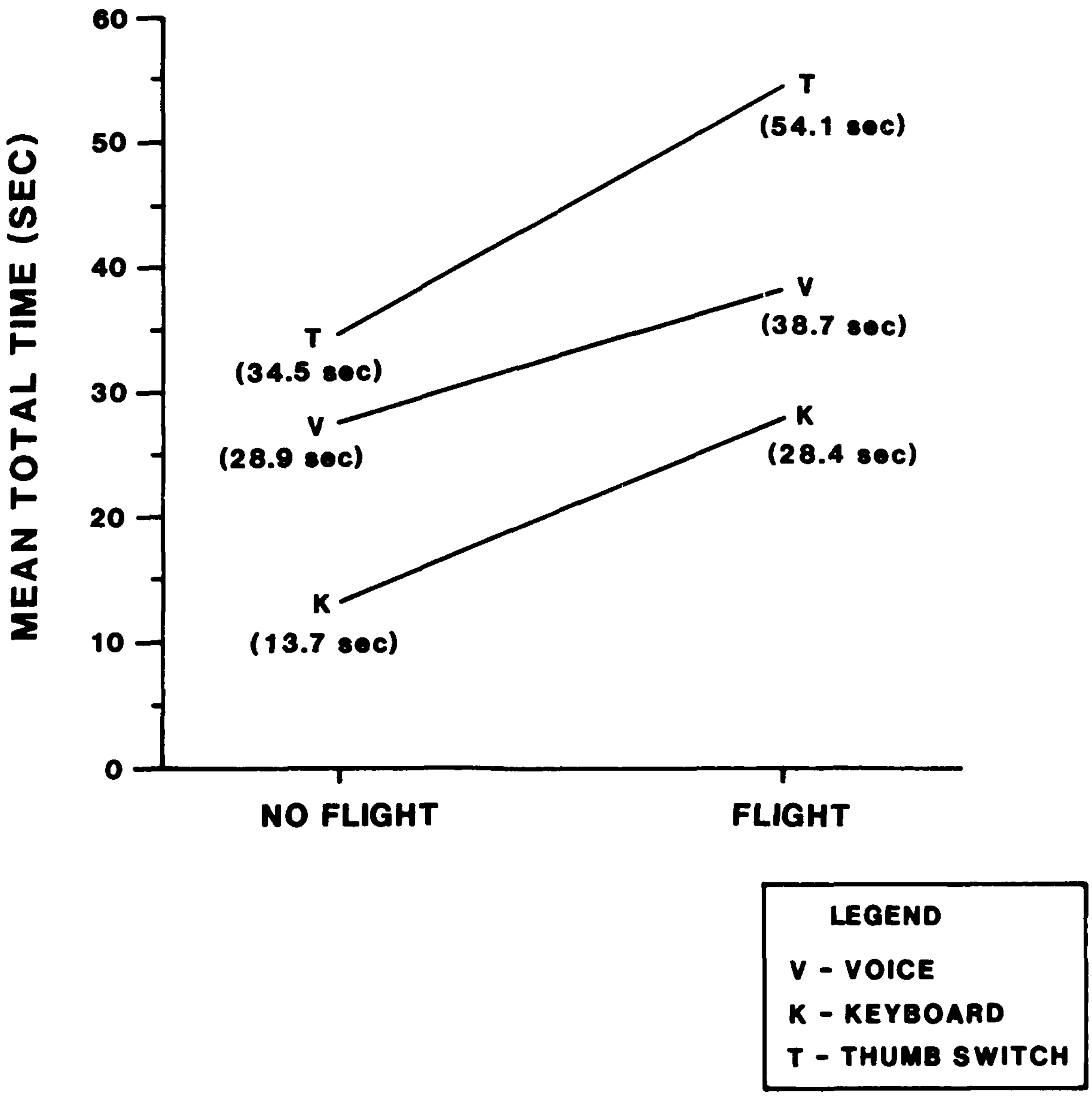

Figure 8. Mean total time.

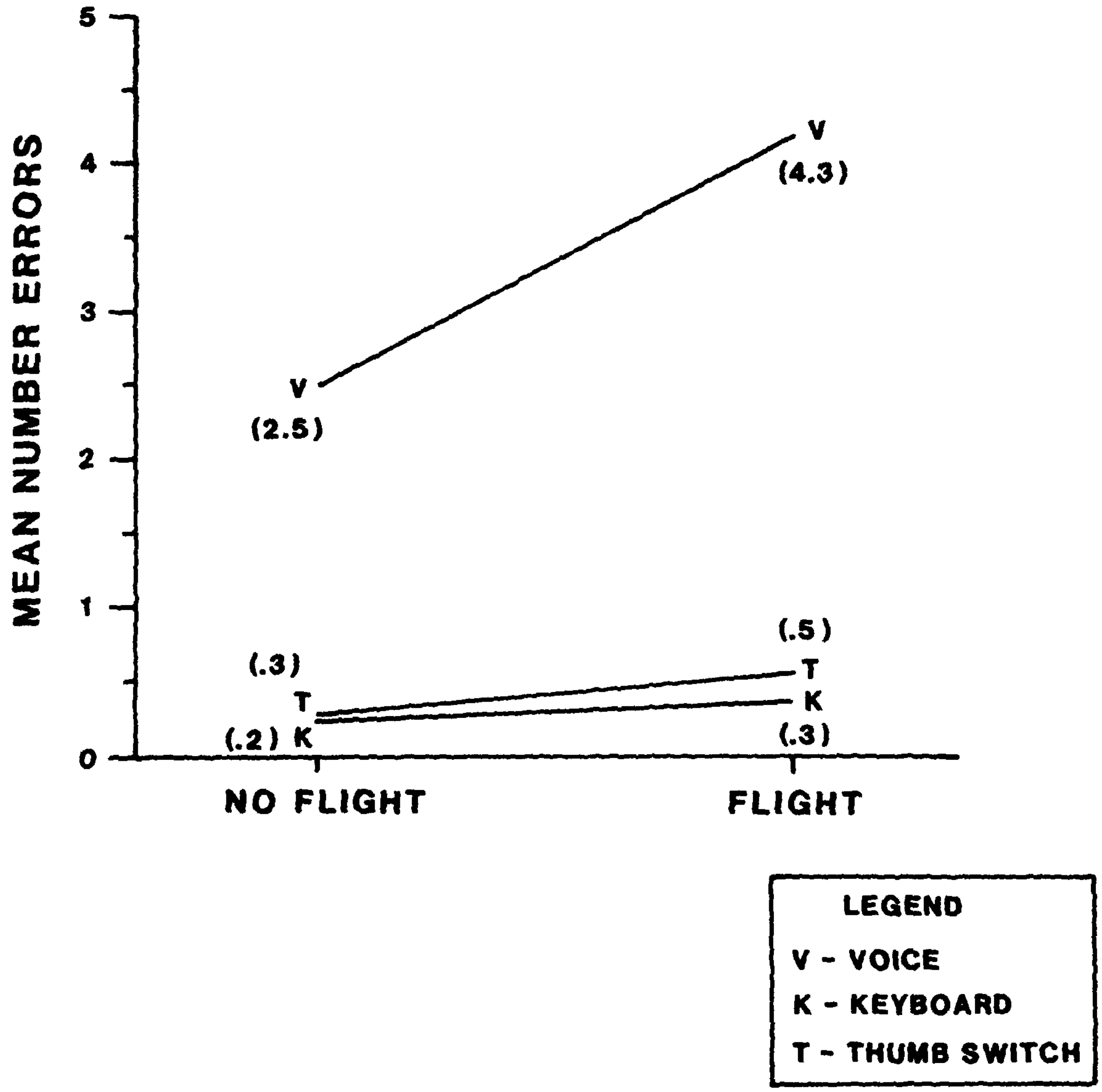

Figure 9. Mean numbers of errors.

Table 1

Data Entry Method By Mean Flight Performance Difference

	Voice	Keyboard	Thumb switch
Airspeed (knots)	-1.13	-3.39	-0.64
Altitude (feet)	5.62	1.83	8.33
Flight path deviation - RMS error (feet)	2.20	19.20	51.30

Flight Path Deviation

There were no significant differences for flight path deviation. The subjects were able to maintain their flight path over the riverbed for each data entry method. Table 1 also contains the average differences in flight path deviation.

Subjective Data

The majority of the pilots preferred to enter the navigational data by voice under both task conditions. The thumb-controlled switch method was the least preferred method. All three methods were viewed as easy to learn to use. The results are shown in Table 2.

DISCUSSION

The objective of this study was to compare the three data entry methods for time and errors when data entry was the sole task and for time, errors, and the effect on flight performance when data entry was performed while flying a helicopter simulator. As the results show, each method had its relative merits.

For response time, subjects were able to respond faster to the prompt to enter data by keyboard when data entry was the sole task performed. The list of coordinate sets was located on a kneeboard positioned on the left leg beside the keyboard. The subjects rested their hands on the keyboard, waiting for the next prompt to occur. The other two methods required the subjects to glance down at the coordinate list and then look up to enter and check the data.

Table 2

Subjective Questionnaire Results (%)

	Voice	Keyboard	Thumb switch
Prefer most (No flight)	70	15	15
Prefer least (No flight)	15	31	54
Prefer most (Flight)	67	16.5	16.5
Prefer least (Flight)	16	42	42
Easiest to learn	44	38	18
Most difficult to learn	36	28	36

These results were reversed when data entry was performed while flying the simulator. The subjects were able to respond to the prompt to enter data faster when using the voice or thumb-controlled switch methods than with the keyboard. The keyboard method required the subjects to remove their hands from the collective and enter data while trying to fly through a simulated low-level flight along a winding riverbed. If the prompt to enter data came at a time in the flight path that required input from the collective, the subjects could not enter the data immediately. The voice and thumb-controlled switch methods did not require the subjects to remove their hands from the flight controls. The subjects could continue to make the necessary flight inputs while responding to the prompt to enter data.

However, once data entry began, the keyboard method resulted in the fastest entry of the navigational data. Very few errors were committed using the keyboard. The majority of the subjects would enter the two alpha characters first, then enter the digits in two groups of four, checking each time for errors. The keyboard was also a more reliable system compared to the voice recognizer. If subjects depressed a key, they were certain to have that character displayed. They could not be assured that the character they spoke would be the one displayed.

The thumb-controlled switch was not quite as reliable as the keyboard either. Some confusion existed over the fact that the clicks that occurred when moving the switch did not necessarily correspond to the scrolling of the characters. The switch needed to be pushed past the location where the click occurred.

Voice data entry was slowed considerably by the low recognition accuracy. In a diagnostic probe of the data, the input time was separated into two groups: error-free input time and input time with errors. No significant difference existed for error-free input time between the keyboard and the voice system (15.8 seconds versus 14.6 seconds, respectively). The thumb-controlled switch method was still significantly slower (39.3 seconds). This would seem to indicate that if a perfect voice recognition system was developed that could correctly accept all inputs made under all conditions and by all speakers, data entry by voice could be as fast as the current keyboard method.

Using connected-word voice recognition to enter long strings of alphanumerics creates an error detection-correction problem. As with the keyboard method, the subjects tended to enter the two alpha characters first, followed by two groups of four digits each. An individual character error could not be detected or corrected until the entire spoken string was recognized. The procedure was very time-consuming. In the instances of insertions and deletions, one error could require the subject to go through the POSITION/MAKE-IT error correction procedure several times to correct one error. At the very least, the subject could clear the display and begin again, which was also time-consuming. The same error could then still occur.

The total time required to enter a coordinate set with the keyboard was significantly faster than both the voice and thumb-controlled switch methods when data entry was a sole task. However, during the flight task condition, there was no statistical difference between the voice and the keyboard, with the thumb-controlled switch still significantly slower. When comparing the mean times for the three methods, a 10-second difference existed between the keyboard and the voice system. It took an average of 28.4 seconds to respond and enter data by the keyboard method compared to 38.7 seconds using the voice data entry method.

One reason there was no statistical difference in flight performance measured across effects could be due to the flight handling qualities of the simulator. The other reason could be that the pilots were instructed to fly and enter data as they would in an operational environment. Thus they gave the flight task their primary attention and entered data only when the aircraft was under reasonable control.

Pilot preference for the method of data entry was not surprising. Even with the high error rate, the majority of the subjects still preferred to enter data by voice. They preferred the voice method because it allowed them to keep their attention focused outside of the aircraft. Although the thumb-controlled switch also permitted more attention focused on the flight rather than on the data entry, the majority of the pilots found it difficult to operate the switch without moving the cyclic. They also detected that the thumb-controlled switch was considerably slower than the other two methods.

CONCLUSIONS AND RECOMMENDATIONS

Although the results point to the fact that entering alphanumeric data by keyboard is faster and less error-prone, pilots required to operate such systems prefer to use voice data entry. It allows pilots to devote more attention to their flight task, thereby reducing the workload associated with time-sharing between two or more tasks. In situations such as low-level or nap-of-the-earth flight, it is almost impossible for a pilot to divert his attention away from the external environment.

However, before a voice recognition system can be used in such environments, recognition accuracy needs to be improved. Perhaps the accuracy could have been increased by limiting the syntax structure of the vocabulary. By giving the pilots as much flexibility as possible in the number of characters that could be entered at one time, recognition accuracy could have been adversely affected.

Overall, based on the results of this study, the use of voice recognition is not recommended for tasks that require the entry of relatively long digit or alphanumeric strings.

An area of connected-word voice recognition that needs to be further investigated is error correction procedures. The POSITION/MAKE-IT method used in this study was time-consuming. Although the subjects successfully used this method during practice sessions, they sometimes forgot the exact wording of the command during the test sessions. In addition, the subjects had to determine the position in the string where the error occurred, adding to the time involved for correcting errors. Alternative methods, perhaps combining a manual device with the voice input, may reduce the time required to correct errors.

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APPENDIX A

BACKGROUND QUESTIONNAIRE

BACKGROUND QUESTIONNAIRE

NAME: ______________________________

AGE: _____

GRADE/RANK: _______________

TOTAL NO. OF YEARS AS A RATED AVIATOR: _____

TOTAL HOURS IN ROTARY WING: __________

TOTAL HOURS IN FIXED WING: __________

AVERAGE NO. OF HOURS YOU ARE CURRENTLY FLYING PER MONTH: __________

DO YOU HAVE ANY EXPERIENCE USING SPEECH RECOGNITION EQUIPMENT?

NONE SOME A LOT

WHEN WAS THE LAST TIME YOU USED A SPEECH RECOGNIZER? __________

DO YOU HAVE ANY EXPERIENCE USING A DATA ENTRY KEYBOARD?

NONE SOME A LOT

WHEN WAS THE LAST TIME YOU USED A DATA ENTRY KEYBOARD? __________

APPENDIX B

VOCABULARY AND GRAMMAR STRUCTURE

VOCABULARY

ALPHA
BRAVO
MIKE
NOVEMBER
ZERO
ONE
TWO
THREE
FOUR
FIVE
SIX
SEVEN
EIGHT
NINER
TEN
CORRECTION
CLEAR
ENTER
POSITION
MAKE-IT

GRAMMAR STRUCTURE

```
.ALPHA @ 2  .DIGIT @ 0,8
.DIGIT @ 1,8
POSITION .PLACE MAKE-IT .ALPHANUM
CORRECTION
ENTER
CLEAR

.ALPHA =
     ALPHA
     BRAVO
     MIKE
     NOVEMBER

.DIGIT =
     ONE
     TWO
     THREE
     FOUR
     FIVE
     SIX
     SEVEN
     EIGHT
     NINER
     ZERO

.PLACE =
     .DIGIT
     TEN

.ALPHANUM =
     .ALPHA
     .DIGIT
```

APPENDIX C

SUBJECTIVE QUESTIONNAIRE

SUBJECTIVE QUESTIONNAIRE

1. WHICH DATA ENTRY METHOD DO YOU PREFER MOST WHEN DATA ENTRY IS THE SOLE TASK?

WHICH THE LEAST?

BRIEFLY EXPLAIN THE REASONS FOR YOUR PREFERENCES.

ADDITIONAL COMMENTS:

2. WHICH DATA ENTRY METHOD DO YOU PREFER MOST WHEN DATA ENTRY IS PERFORMED WHILE FLYING?

WHICH THE LEAST?

BRIEFLY EXPLAIN THE REASONS FOR YOUR PREFERENCES.

ADDITIONAL COMMENTS:

3. IN YOUR EXPERIENCE TODAY, WHICH DATA ENTRY METHOD WAS THE EASIEST TO LEARN TO USE?

WHICH WAS MOST DIFFICULT?

BRIEFLY EXPLAIN THE REASONS FOR YOUR CHOICES.

ADDITIONAL COMMENTS:

APPENDIX D

MULTIVARIATE ANALYSIS OF VARIANCE (MANOVA) RESULTS

MANOVA RESULTS

Statistical Significance Of Factors By Dependent Measures

Dependent Measures	F-Statistics	Subject Significance α = .05
Response Time	8.64	*
Input Time	5.57	*
Total Time	7.70	*
Total Errors (Log)	2.78	*
Dependent Measures	**F-Statistics**	**Method Significance α = .05**
Response Time	1.07	*
Input Time	30.78	*
Total Time	34.26	*
Total Errors (Log)	20.30	*
Dependent Measures	**F-Statistics**	**Task Significance α = .05**
Response Time	29.25	*
Input Time	20.21	*
Total Time	31.17	*
Total Errors (Log)	3.41	-

Note. * denotes statistical significance.
- denotes no statistical significance.

(table continues)

Dependent Measures	Method By Task F-Statistics	Significance α = .05
Response Time	11.7	*
Input Time	2.25	-
Total Time	2.48	-
Total Errors (Log)	2.84	-

Dependent Measures	Subject By Method By Task F-Statistics	Significance α = .05
Response Time	1.13	-
Input Time	1.00	-
Total Time	.97	-
Total Errors (Log)	1.03	-

Dependent Measures	Subject By Task F-Statistics	Significance α = .05
Response Time	4.09	*
Input Time	2.45	*
Total Time	3.11	*
Total Errors (Log)	1.50	-

Dependent Measures	Subject By Method F-Statistics	Significance α = .05
Response Time	3.15	*
Input Time	2.09	*
Total Time	2.26	*
Total Errors (Log)	3.19	*

MANOVA RESULTS

Statistical Significance Of Factors By Dependent Measures

Dependent Measures	Subject	
	F-Statistics	Significance α = .05
Speed Difference	1.57	.107
Altitude Difference	1.84	.048
Error Difference	1.26	.247
	Method	
Dependent Measures	F-Statistics	Significance α =.05
Speed Difference	1.12	.342
Altitude Difference	2.98	.071
Error Difference	2.92	.075
	Subject By Method	
Dependent Measures	F-Statistics	Significance α = .05
Speed Difference	1.11	.332
Altitude Difference	.72	.812
Error Difference	.81	.70

APPENDIX E

MEAN, STANDARD DEVIATION, AND CONFIDENCE
INTERVAL TABLES

RESPONSE TIME

NO FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	2.34	1.26	2.085	2.597
Keyboard	1.23	.75	1.085	1.389
Thumb-controlled switch	1.97	1.89	1.591	2.355

FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	3.53	3.32	2.830	4.239
Keyboard	6.72	6.65	5.376	8.070
Thumb-controlled switch	5.54	7.06	4.067	7.008

INPUT TIME

NO FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	26.56	21.77	22.147	30.970
Keyboard	12.46	4.77	11.493	13.426
Thumb-controlled switch	32.50	7.28	31.027	33.977

FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	35.17	34.80	27.792	42.541
Keyboard	21.70	11.02	19.468	23.933
Thumb-controlled switch	48.51	19.45	44.464	52.563

TOTAL TIME

NO FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	28.90	21.88	24.466	33.334
Keyboard	13.70	4.86	12.711	14.681
Thumb-controlled switch	34.47	7.07	33.042	35.908

FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	38.70	35.76	31.125	46.277
Keyboard	28.42	13.98	25.592	31.256
Thumb-controlled switch	54.05	21.63	49.547	58.555

ERRORS (LOG)

NO FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	2.48	.28	2.425	2.537
Keyboard	2.32	.07	2.308	2.338
Thumb-controlled switch	2.33	.07	2.317	2.346

FLIGHT

	Mean	Standard Deviation	95% Confidence	Interval
Voice	2.57	.39	2.483	2.648
Keyboard	2.33	.08	2.311	2.342
Thumb-controlled switch	2.35	.08	2.332	2.367